RADAR: An In-Building RF-based User Location and Tracking System

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Infocom 2000

Tel Aviv, Israel

March 2000

Outline

- Motivation and related work
- RADAR
  - generating a radio map
  - NNSS algorithm
- Performance evaluation
- Summary and follow-on work

Motivation

- Location-aware services are a key ingredient of mobile computing
- Determining user location is a prerequisite to building such services
- Solutions designed for the outdoors (e.g., GPS) are ineffective indoors

Related Work in Indoor Positioning Systems

- Infrared-based systems (e.g., Active Badge)
  - Accurate due to short range and line-of-sight property
  - But scales poorly & requires specialized infrastructure
- Radio Frequency-based systems
  - Cell-level granularity using point of attachment
  - Duress Alarm Location System, PinPoint
- Alternative technologies: magnetic, optical, acoustic
  - Very accurate (mm to cm resolution)
  - But requires dedicated infrastructure
  - Targeted at specialized applications, e.g., head tracking

Traditional approach has been based on dedicated technology and infrastructure

Our Approach

- Leverage *existing* infrastructure
- Use an off-the-shelf RF wireless LAN
- Several advantages
  - WLAN deployed primarily to provide data connectivity
  - software adds value to wireless hardware
  - better scalability and lower cost than dedicated technology

RADAR

- Key idea: signal strength matching
- Offline calibration:
  - tabulate <location,SS> to construct *radio map*
- Real-time location & tracking:
  - extract SS from base station beacons
  - find table entry that best matches the measured SS

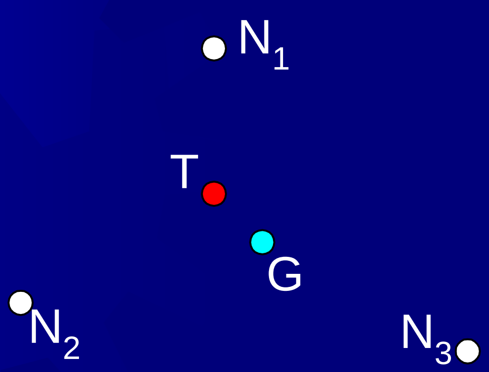
Constructing a Radio Map

- Empirical method
  - measure SS at various locations using BS beacons
  - record SS along with corresponding coordinates
    - user orientation needs to be included too!
    - tuples of the form $(x,y,z,d,s_1,\ldots,s_n)$
  - accurate but laborious
- Mathematical method
  - compute SS using a simple propagation model
    - factor in free space loss and wall attenuation
    - apply Cohen-Sutherland line clipping algorithm on building layout
  - more convenient but less accurate

$$P(d)[dBm] = P(d_o)[dBm] - 10n\log\left(\frac{d}{d_o}\right) - \begin{cases} nW * WAF & nW < C \\ C * WAF & nW \geq C \end{cases}$$

Determining Location

- Find nearest neighbor in signal space (NNSS)
  - default metric is Euclidean distance
- Physical coordinates of NNSS $\Rightarrow$ user location
- Refinement: *k*-NNSS
  - average the coordinates of *k* nearest neighbors

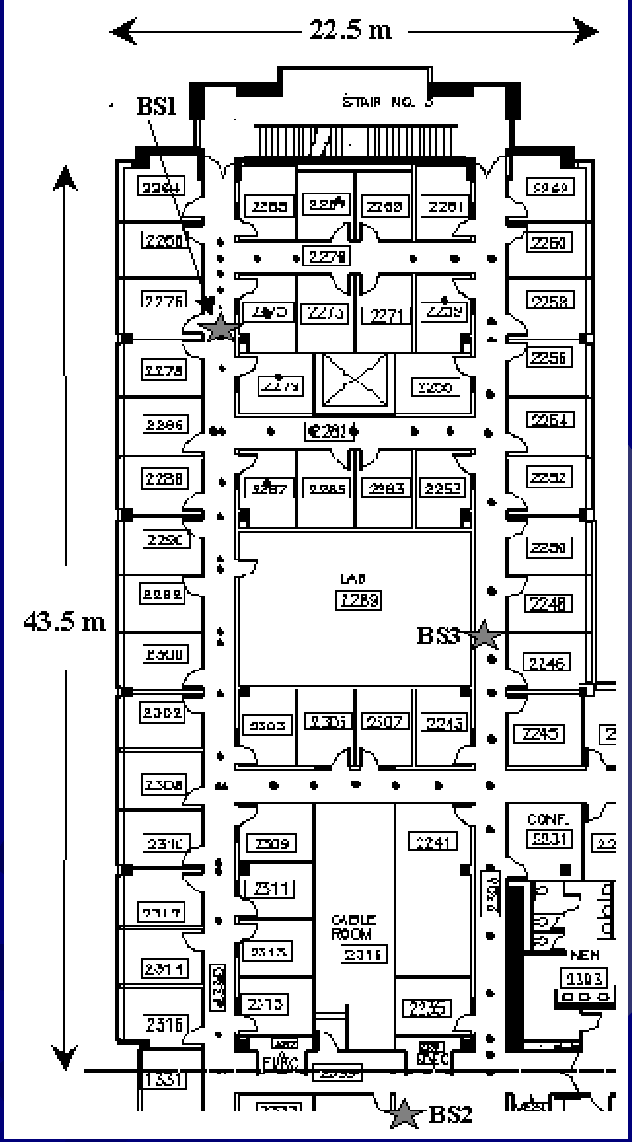


N_1, N_2, N_3: neighbors
T: true location of user
G: guess based on averaging

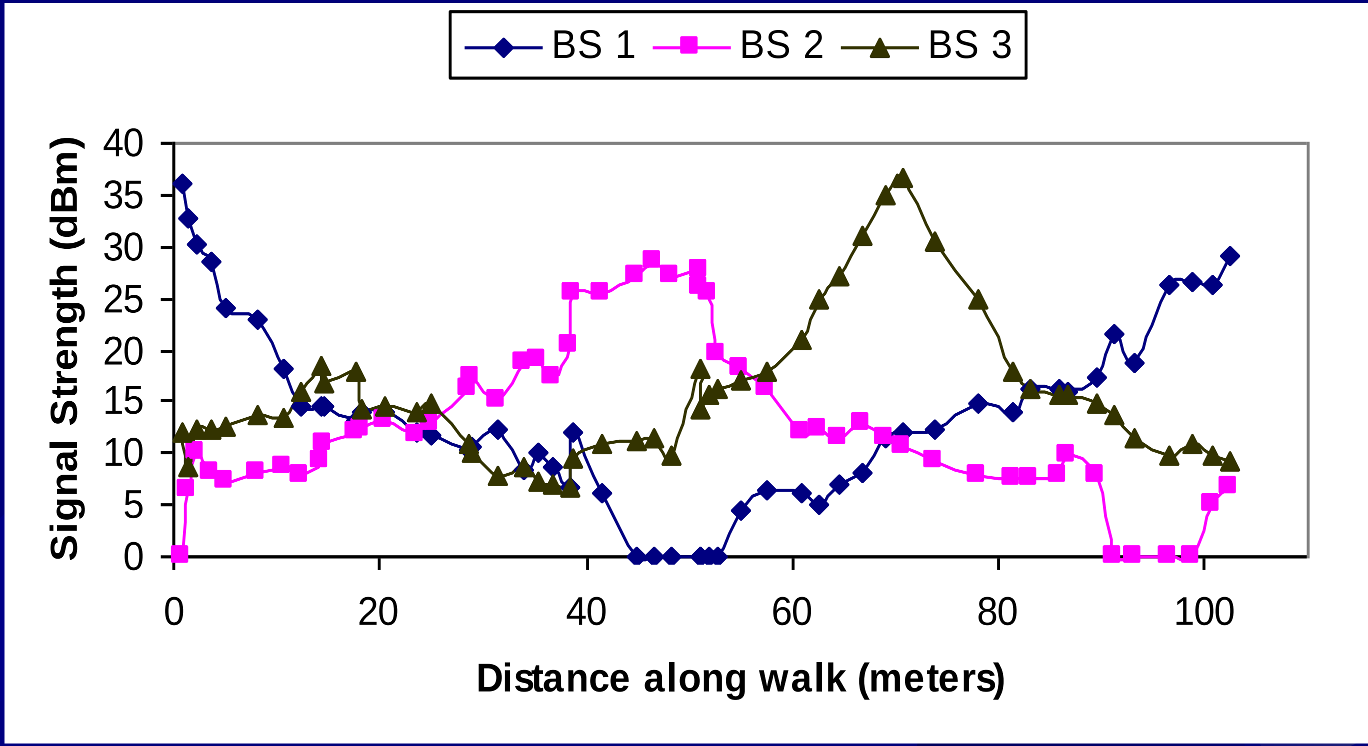
Microsoft Research Radar

Experimental Setting

- Digital RoamAbout (WaveLAN)
- 2.4 GHz ISM band
- 2 Mbps data rate
- 3 base stations
- 70x4 = 280 (x,y,d) tuples



How good an indicator of location is signal strength?



Signal strength correlates well with location

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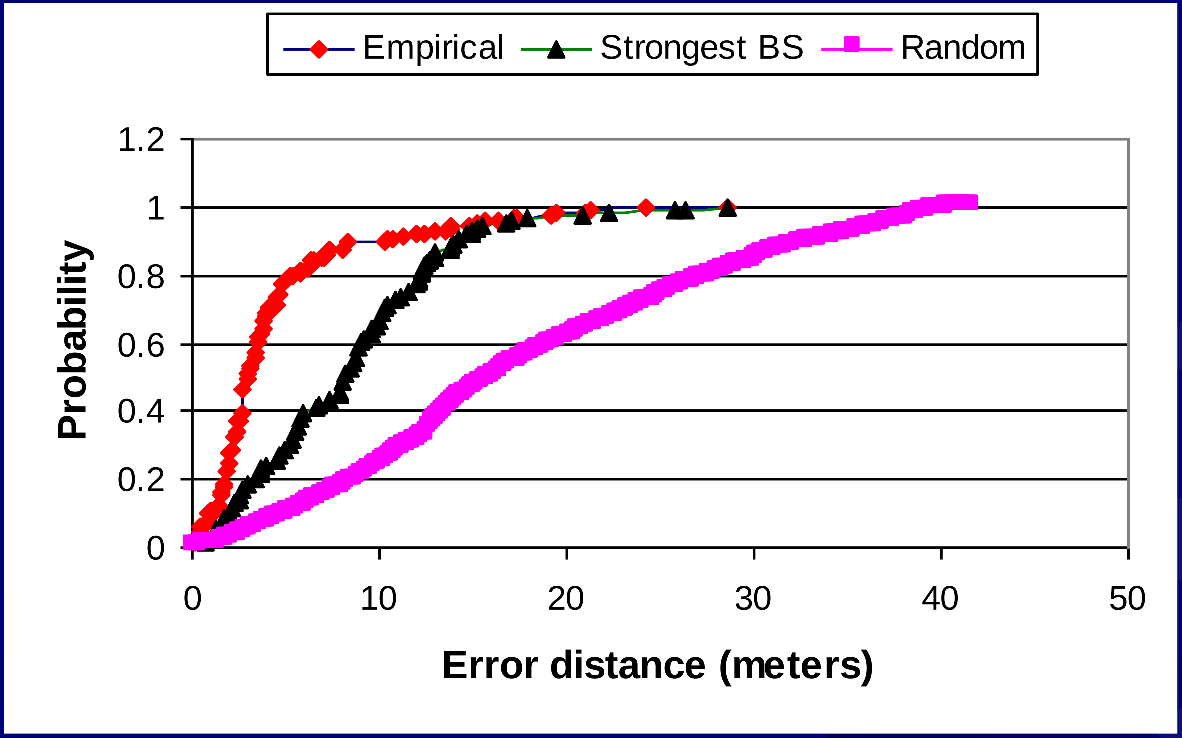
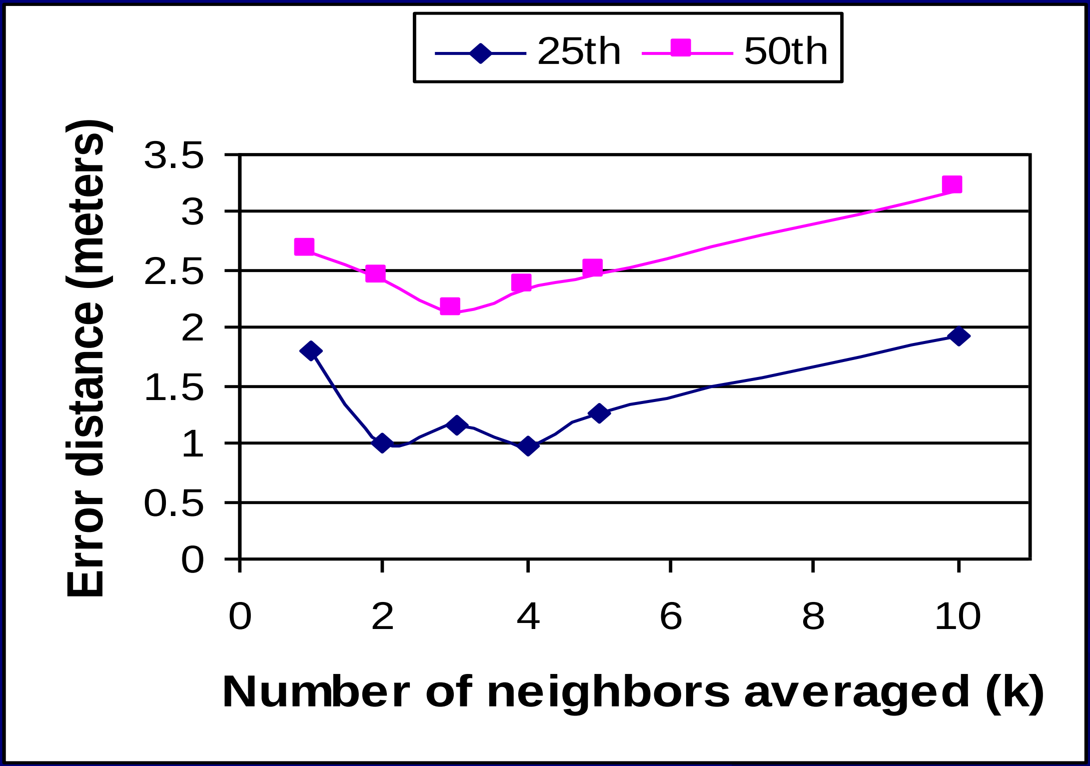
Baseline Performance



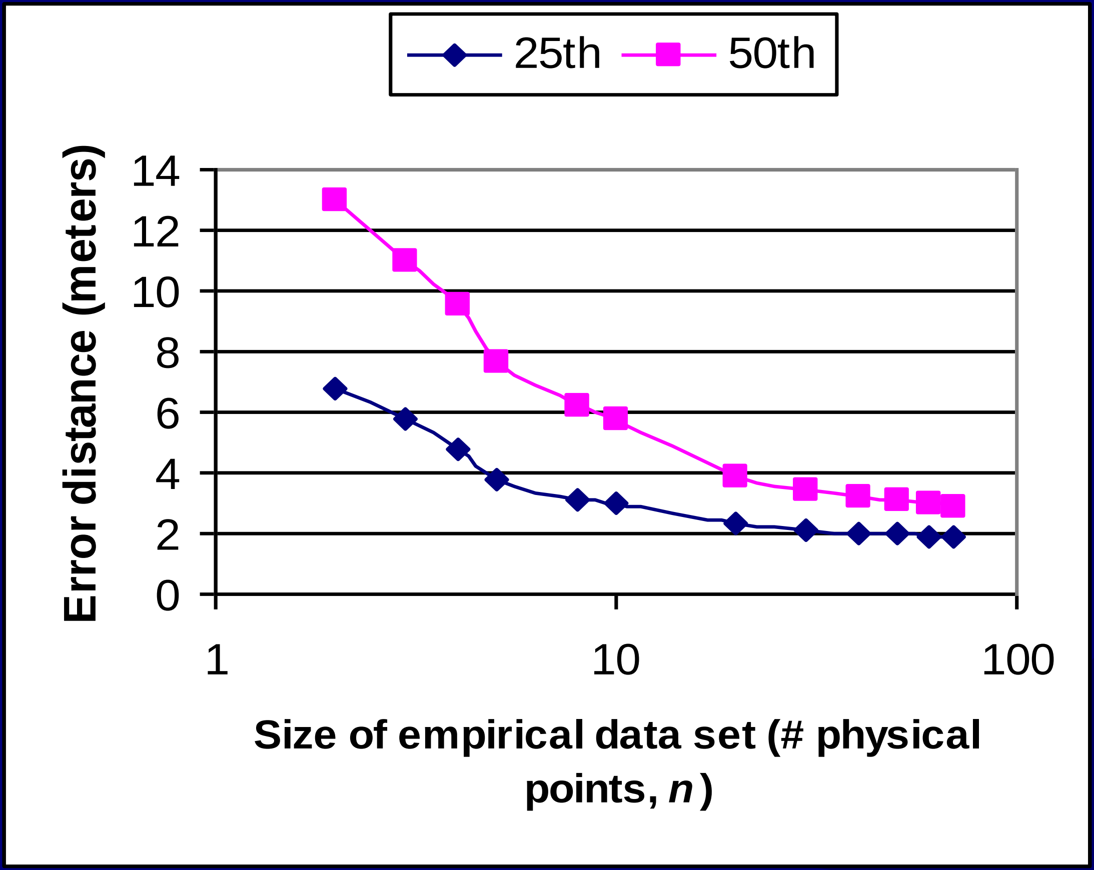
Median error distance is 2.94 meters

Performance with averaging



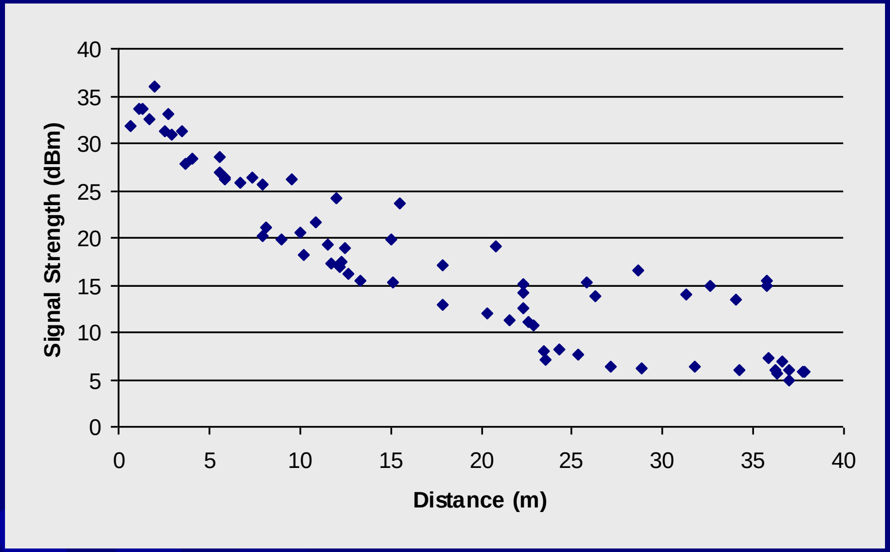
Median error distance is 2.13 meters when averaging is done over 3 neighbors

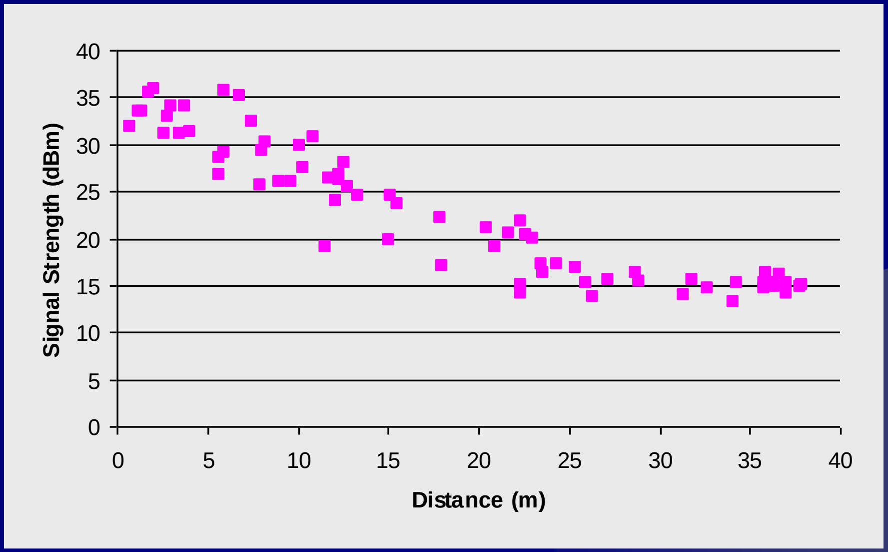
How extensive does the Radio Map have to be?



Diminishing returns as the number of physical points mapped increases

Signal Propagation Model

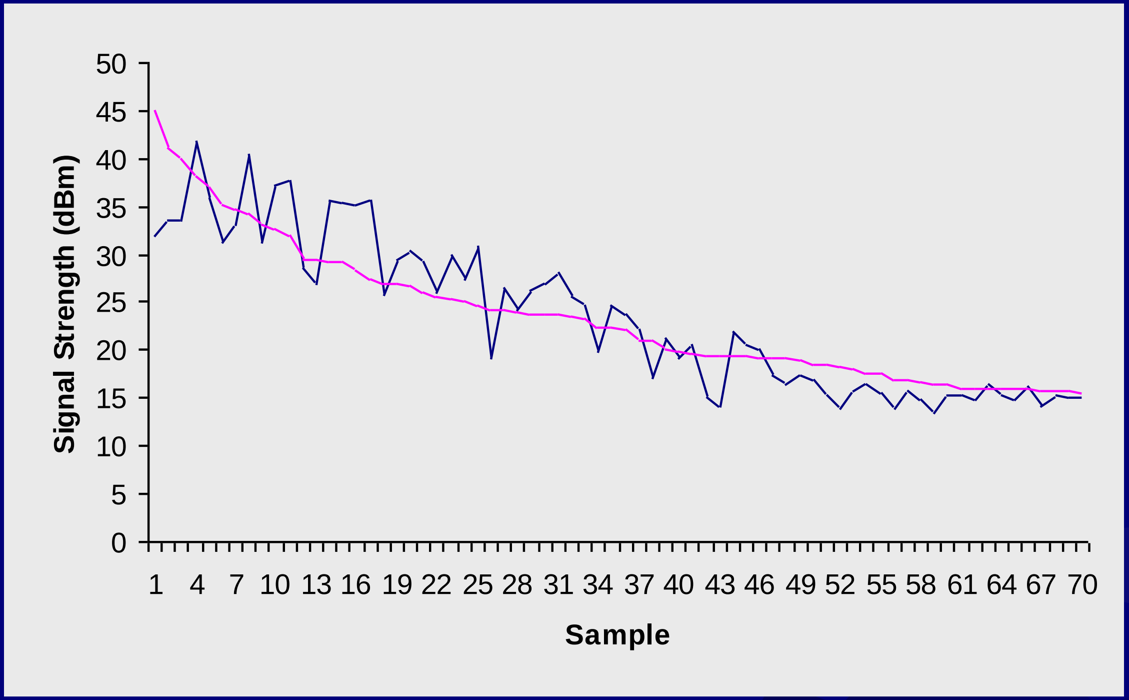




$$P(d)[dBm] = P(d_o)[dBm] - 10n\log\left(\frac{d}{d_o}\right) - \begin{cases} nW * WAF & nW < C \\ C * WAF & nW \geq C \end{cases}$$

Model parameters: $P(d_0)$ = 58 dBm, n = 1.53, WAF = 3.1 dBm, C = 4 walls

How well does it work?



Median error distance is 4.94 m compared to 2.94 m with empirically constructed radio map and 8.16 m with nearest base station method

Summary

- Determine user location via signal strength matching
- Radio map constructed via empirical measurements or mathematical modeling
- Median error 2-3 meters with empirical map
- Leverages existing wireless LAN infrastructure
  - wireless hardware agnostic

RADAR: a software solution to indoor location determination

RADAR++

- Probabilistic modeling of user motion
  - models constraints imposed by building geometry
  - thins down the tail of the error distance CDF
- Environmental profiling
  - adapts the system to varying radio environment
- Multiple floors

MSR Technical Report MSR-TR-2000-12

For more info

- Visit *http://www.research.microsoft.com/sn/*
- Email *{bahl,padmanab}@microsoft.com*